SGP4 Propagation of GEO Satellites and Debris

Cody Laakkonen
Mentor: Dr. Richard Linares
Department of Aerospace Engineering & Mechanics, University of Minnesota

Abstract

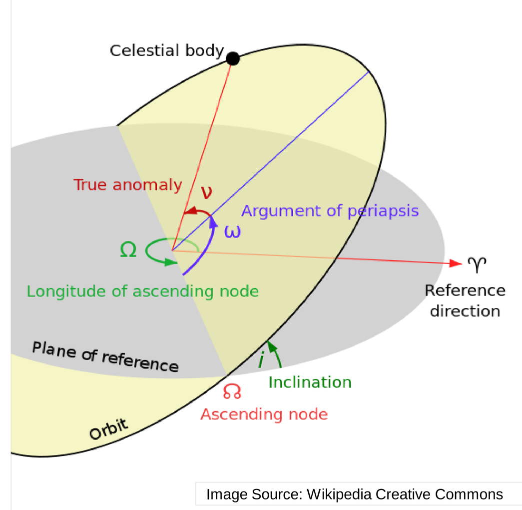
By studying the long-term and short-term changes in 6 Keplerian orbital elements of satellites and debris near Geosynchronous Earth Orbit, this research provides insights on the accuracy of propagated data using SGP4 and TLE data provided by celestrak.com and space-trak.org. Periodic forces, such as that provided by solar forces and the moon's pull, will create changes in a satellites orbit. Many of these periodic forces are approximated when using an SGP4 algorithm, and the accuracy of approximations begins to deteriorate rapidly as you get further from observed data.

Orbital Elements

There are 6 orbital elements that need to be known to uniquely determine the position and trajectory of a satellite at a given time.

In Cartesian coordinates, we use:
- X,Y,Z Positions
- X,Y,Z Velocities

In Keplerian elements, we use:
- Semi-Major Axis
- Argument of Perigee
- Right Angle of Ascending Node
- True Anomaly
- Inclination
- Eccentricity



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Problem Statement

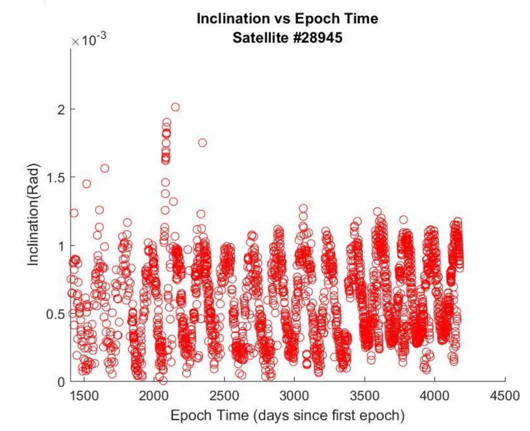
- Satellite and debris collisions threaten the continued use operation of current and future satellites present in Earth orbit.
- Threat of collision is particularly notable in highly populated orbits, such as GEO
- Predicting where satellites and debris will be at a future time is subject to potentially large degrees of uncertainty

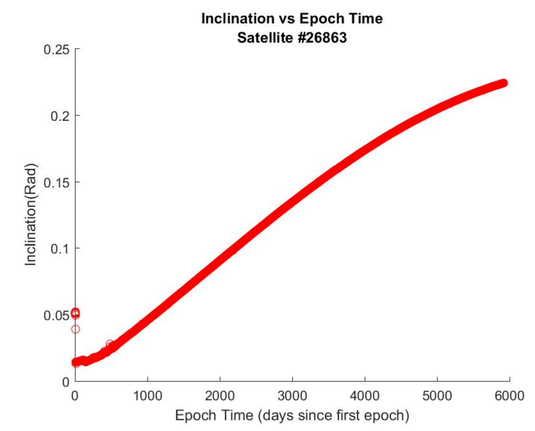
Methods

To evaluate the changes made during a satellite's time in orbit, MATLAB functions were created to use with SGP4 propagators and written using information from David Vallado's "Fundamentals of Astrodynamics and Applications" (1997). A script was written to take and parse information from TLE's and extract the 6 Keplerian Elements of interest and compute 6 Cartesian Elements. This information is passed into an SGP4 propagator which numerically integrates equations of motion and saves the results. A plotter is then called to plot the information. A few extra functions were created, such as an error checking function which throws errors when it detects bad data.

Inclination

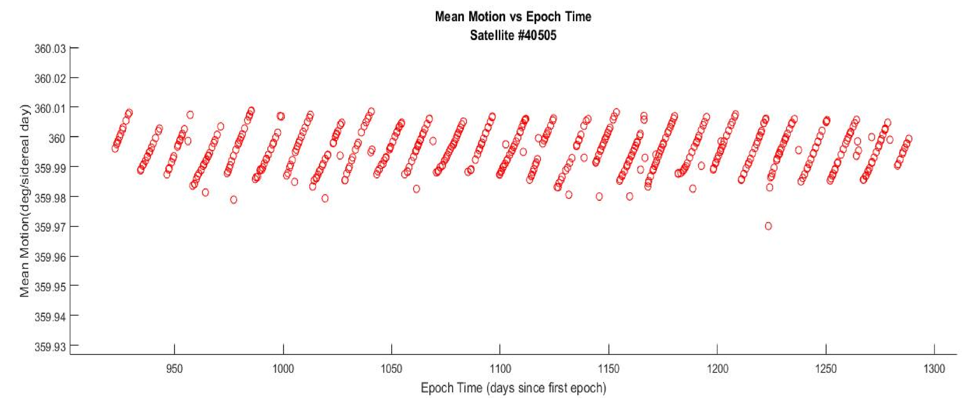
Inclination for GEO satellites is kept very close to 0 because this keeps the satellite in the same position in the sky to a viewer from earth. However, the inclination does vary slightly. Below you can see the inclination of Spainsat #28945 and Artemis #26863 changing over several thousand days. Spainsat is maneuvering and Artemis is drifting freely.





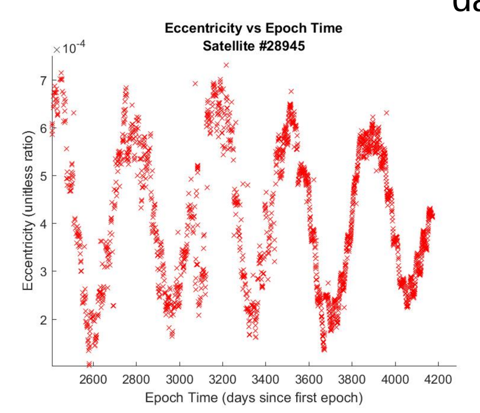
Mean Motion

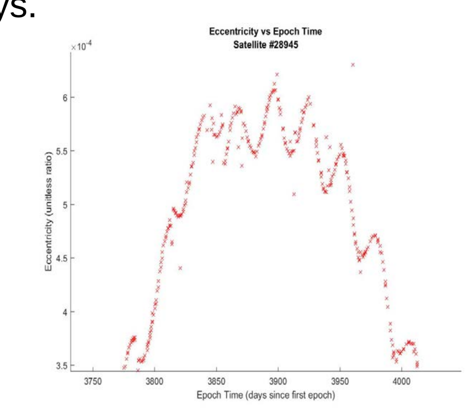
Mean Motion describes the rate at which a satellite is orbiting the earth. For GEO this should be maintained at 360 degrees per 1436.1 minutes (one sidereal day). You can see that it tends to drift upward and is corrected to 360 degrees per sidereal day. This this observed effect is also due to maneuvering by the satellite operators. Mean Motion for satellite 40505, Express AM-7 is shown below.



Eccentricity

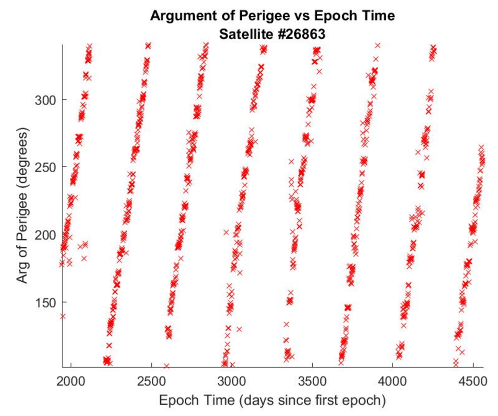
Eccentricity describes how circular or not circular an orbit is and has a possible range between 0 and 1 in dimensionless units. For orbits near GEO, this value should be maintained at or near 0. The below is data from satellite 28945, SpainSat and shows the periodic changes in eccentricity over hundreds of days as well as the periodic changes that occur with a period of about 30 days.

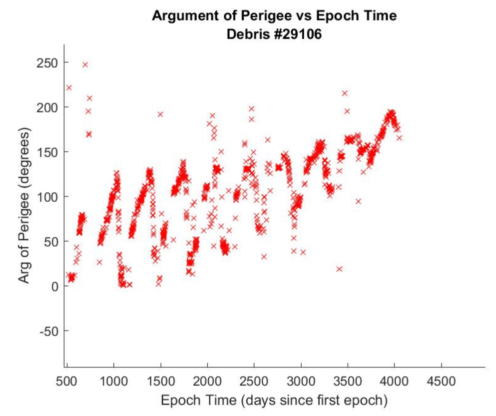




Argument of Perigee

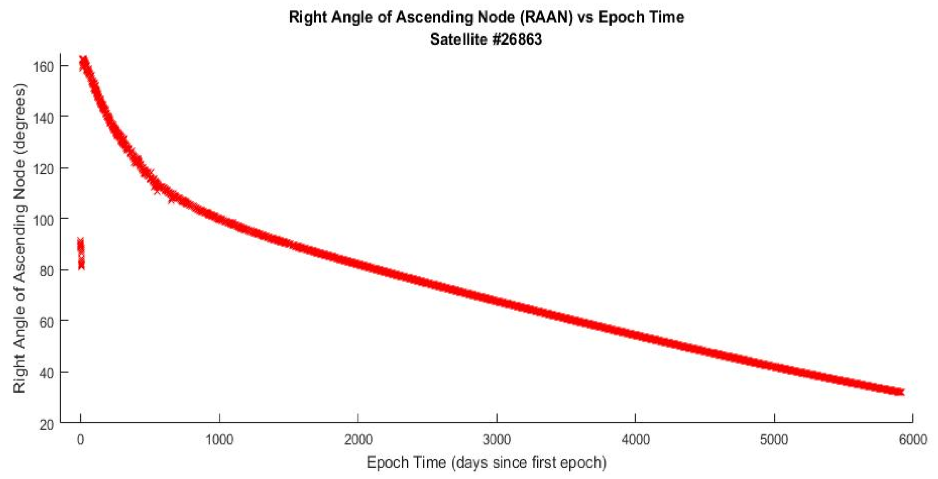
Argument of Perigee is an angle that describes the location of the Perigee with reference to the Ascending Node. Shown below is the Argument of Perigee for Artemis #26863 and for a particular piece of debris from satellite MSG-2 #29106. The patterns for how the Argument of perigee changes with time is drastically different for these two satellites, despite both being in GEO. Artemis has a cross sectional area of $10m^2$ while the MSG-2 debris has a cross section of $.003m^2$.





Right Angle of the Ascending Node

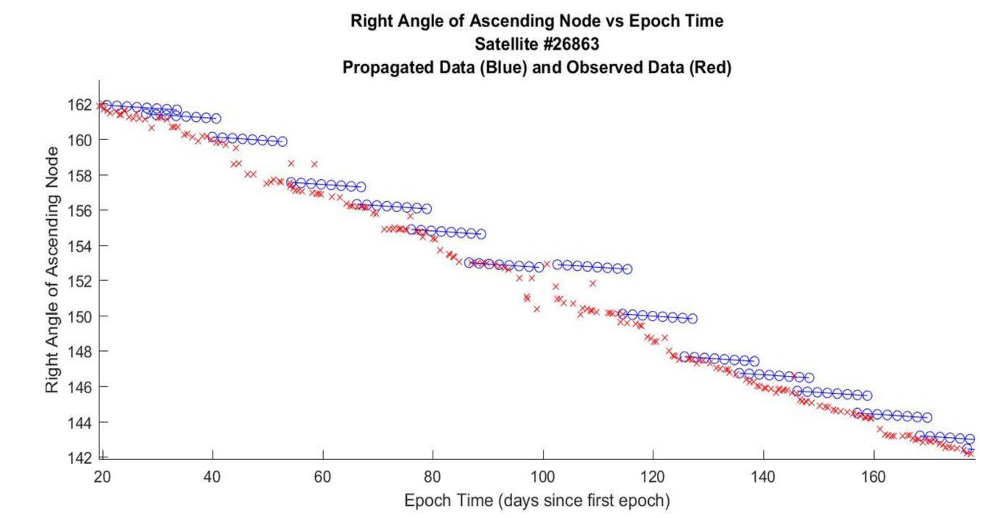
Right angle of the Ascending Node (RAAN) is an angle used to describe the position of the Ascending Node. The RAAN is an angle measured from a reference direction (in the case of Earth-orbits this is typically the "First Point of Aries") to the Ascending Node following right-hand conventions. Shown Below is the change in RAAN for satellite 26863 Artemis over a 6000 day period.

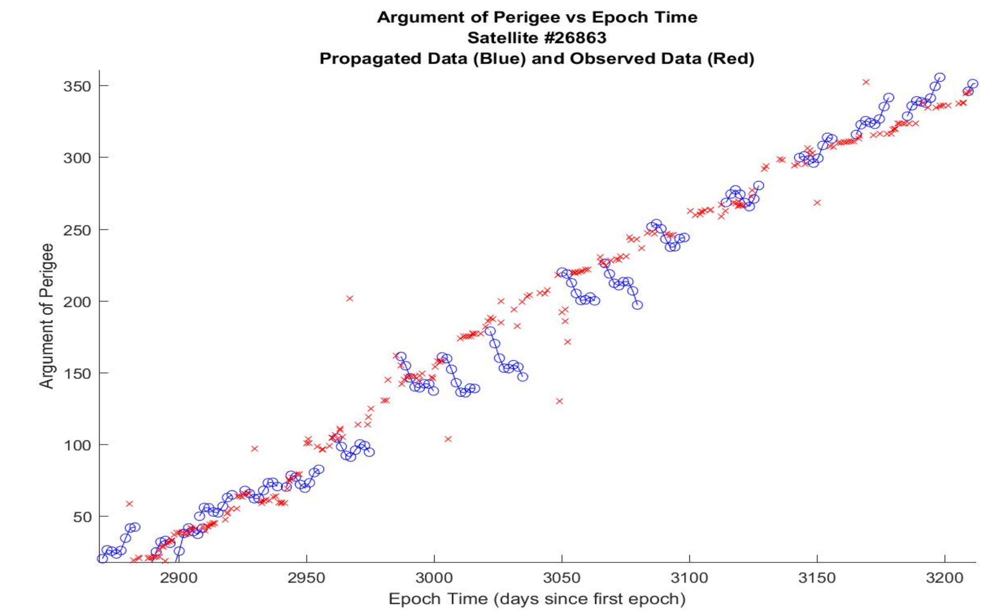


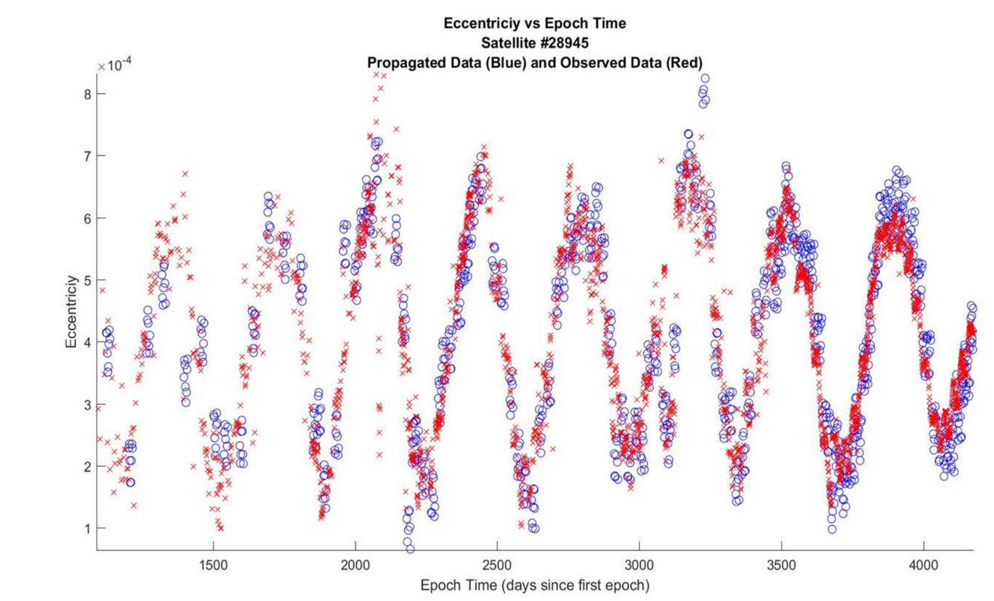
Propagation

In the process of predicting how these orbital elements will change, the SGP4 propagator attempts to reintroduce some of the periodic effects needed. You can see below a few examples where the propagated data (in blue) attempts to account for periodic forces in between data points from the data presented earlier for satellite 28945 and 40505. In some cases, the propagated data comes very close to reality. In other cases, the propagation algorithm is less accurate. Examples below show both cases.

Propagation Results







Conclusion

The ability to continue using satellites in all orbits will increasingly require accurate predictions for collision avoidance as well responsible use of common orbits. While SGP4 provides accurate data for short time spans and for objects with a low area-to-mass ratio, it is shown that accuracy for high area-to-mass objects deteriorates even for small time spans.

Acknowledgements

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